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Loss of nitrogen and bases after fertilization of second-growth hardwood forest soils[1]

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Abstract

Soils at five New York sites of a nitrogen fertilization study in second-growth mixed deciduous forests were sampled to determine the fate of applied N and possible adverse chemical changes from its application. Organic layer and mineral soil (0–10 cm) samples were collected 10 or 11 years after the initial application from plots receiving a total of 0, 672 and 1344 kg-N ha^{-1} in two equal-sized applications 5 years apart. Nitrogen was applied as ammonium nitrate, except the first application at one location was urea. Treatments had little effect on the N and C pools of the forest floor and surface soil, indicating no appreciable retention of added N in the upper soil. Concentration and mass of cations in the mineral soil decreased with added N, as did pH, in accord with an hypothesis of nitrate leaching. The estimated loss of base cations was modest (12.4 kmol(+) ha^{-1}) relative to the anions added in the highest single application of N (24 kmol(−) ha^{-1}). On such soils, N added in excess of plant uptake capacity is not immobilized by long-term storage in soil organic matter despite its wide C:N ratio. The reduction in pH entails a loss of effective cation exchange capacity in addition to the associated loss of base cations.

Keywords: Nitrogen; Fertilization; Second growth; Soil

1. Introduction

Forest ecosystems are considered to conserve nutrients, cycling them tightly within and between soil and vegetation (Switzer and Nelson, 1972; Henderson and Harris, 1975; Ulrich, 1976; Stone and Kszystyniak, 1977). Recovery of applied fertilizer N by the forest overstory, however, appears low. Tracer studies with conifers indicate no more than 23% recovery in the first year following treatment (Bjorkman et al., 1967), although actual plant uptake may be underestimated by tracer experiments. Plants on the whole are poor competitors with soil heterotrophs for added N (Jansson, 1958). Further, added nitrate is subject to immediate leaching unless absorbed by plant roots or incorporated into microbial tissue (Cole and Gessel, 1965; Overrein, 1971a, b). Other studies have shown that even when the N source is an ammonium salt, recovery of ^{15}N generally will be no greater than 50% for the ecosystem as a whole (Mead and Pritchett, 1975a, b; Johnson, 1992). Nitro-

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gen absorbed by plants and immobilized into microbial tissue is returned to the general pool of soil N over the years. Except in extremely acid soils, excess NH_4-N will nitrify, increasing nitrate levels on fertilized plots, and thus extending the potential for leaching beyond the immediate posttreatment period.

Our studies of increasing rates of fertilizer N applied to natural second-growth stands in New York (Stanturf et al., 1989) revealed only small or zero growth responses of white ash (*Fraxinus americana* L.) and black cherry (*Prunus serotina* Ehrh.) at four locations, and of sugar maple (*Acer saccharum* Marsh.) at seven locations. These results contrasted with significant growth increases of the same species elsewhere in the state (Mitchell and Chandler, 1939).

The lack of detectable responses raised questions about the fate of the applied N as well as the possibility of adverse chemical changes associated with its application. A major concern was whether addition of fertilizer N had altered the large pool of N and C represented by the forest floor and surface soil OM. The possible effects may be stated as five hypotheses.

(1) The total mass of N would increase either as a result of immobilization of added N in the organic matter or through greater litter crop. Increased percentage of N in litter from fertilized trees (Tamm, 1971; Miller et al., 1976) would increase soil N mass. Any increase should be detectable in either the organic layer or the upper mineral soil, or the two layers combined.

(2) The OM mass of the organic layer or mineral soil would either increase as a result of greater productivity and litter return, or decrease because of more rapid decomposition (Safford, 1974). If the mass of the organic layer increased but that of the mineral soil decreased, the combined total might remain unchanged.

(3) The N concentration of the organic matter would increase (i.e. C:N decrease) as a result of immobilization of fertilizer N. This might be independent of changes in total mass of either OM or N but not both. Again, effects could be different in the two soil layers.

(4) There would be no net retention of added N in the organic layer or upper mineral soil.

(5) Random variability would be too high for any changes to be distinguished.

If much of the added N was leached as the nitrate ion (a consequence of hypothesis (4)), the content of basic cations would have decreased and the pH lowered as has been well demonstrated both by lysimeter studies (Raney, 1960; Terman, 1977) and in forests (Broadfoot, 1966; Van Miegroet and Cole, 1984).

2. Materials and methods

2.1. Experimental locations

Four of the original seven locations were chosen for intensive soil sampling because they had received the full range of application rates and were well distributed geographically (Fig. 1). No samples had been taken prior to fertilizer treatment, thus comparisons between control and fertilized plots 10–11 years after initial treatment assume that all plots at a location were from the same pretreatment population.

Complete descriptions of the stands are given elsewhere (Stanturf, 1983; Stanturf and Stone, 1985; Stanturf et al., 1989). An important feature is that all stands were essentially undisturbed for 45 years, except for non-commercial and some light commercial thinning. Elevations of the stands ranged from 292 to 692 m, and average annual precipitation was from 890 to 1151 mm.

The soils were typical of the better northern hardwood forest sites. All were developed in glacial till derived from sedimentary rocks, although the Cattaraugus sites were at the southern limit of glacial expansion and soils there are considered to be developing in residuum (untransported parent material). The soil series and taxonomic classification at each of the four follow.

Chenango: Bath silt loam, well-drained coarse-loamy, mixed, mesic Typic Fragiochrepts. Analyses of a profile from an unfertilized area (Table 1) illustrates the strong acidity and concentration of exchangeable bases in the uppermost

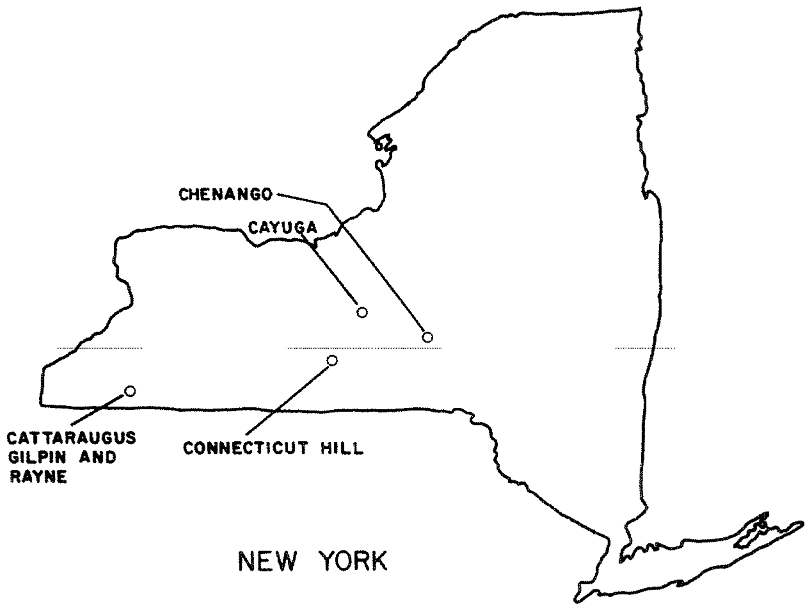

Fig. 1. Map of New York showing the study locations.

mineral layer. The other soil series do not differ greatly in these respects (Table 2).

Connecticut Hill: Mardin silt loam, moderately well-drained, coarse-loamy, mixed, mesic Typic Fragiochrepts associated with the Bath series.

Cayuga: Langford channery silt loam, moderately well-drained fine-loamy, mixed, mesic Aqueptic Fragiudalfs.

Cattaraugus: The experimental plots had been established along a boundary between two slope positions. Subsequent study by the Soil Conservation Service and the senior author established the presence of two series: Gilpin channery silt loam on the upper slope and Rayne silt loam on the lower. Both are fine-loamy, mixed mesic Typic Hapludults but Gilpin is shallower to the fractured bedrock. For convenience, plots on the two soils are discussed as separate locations, making a total of five experimental sites.

2.2. Experimental design

Fertilizer treatments were two applications of N, 0, 336 and 672 kg ha^{-1} N, added as ammonium nitrate (except that the first application at Connecticut Hill was urea) 5 years apart, giving total additions of 0, 672 and 1344 kg N ha^{-1}. The first applications were made between April and August, the second in April and May.

At four locations, the measurement plots were either 0.04 or 0.06 ha in area with 2.25 to 3.0 m wide treated borders and a 3–10 m separation between gross plots. Because the Cayuga stand contained numerous larger trees up to 40 cm dbh, the measurement plots were 0.16 ha in area, with 1.2 m wide treated borders and 10 m separations between gross plots.

For the present study, soil samples were collected from 26 plots, either 10 or 11 years after the first N application. This number includes two replications per treatment at each location plus two extra controls at Chenango. At Cattaraugus, one control and one 1344 kg ha^{-1} plot occurred on the Rayne soil, with the remaining four plots on the Gilpin soil.

Ten subsampling points were randomly located in each plot according to a sampling protocol designed to minimize natural variability not associated with treatments. Treefall pits and mounds were avoided as were rotten wood in the

Table 1
Chemical characteristics of the Bath channery silt loam profile at the Chenango location

Layer (cm)	Horizon	OM (%)	N (%)	pH	Ex. H ($mg\ kg^{-1}$)	Extractable P ($mg\ kg^{-1}$)	K	Ca	Mg
3–0	O_2	51	1.5	3.9					
0–8	A_1	42	1.2	3.6	55	28	315	850	215
8–13	A_2	4	0.2	3.5	18	1	50	200	38
13–15	Bh_{ir}	11	0.5	3.7	51	2	45	180	40
15–33	B_{ir}	6	0.2	4.4	43	1	20	40	8
33–48	B_{21}	4	0.1	4.7	26	1	13	10	5
48–79	B_{22}	2	0.1	4.9	14	1	20	10	3

Table 2
Chemical characteristics of organic layers and mineral soil of the control plots at each location

Variable	Cattaruagus Gilpin	Cattaraugus Rayne	Connecticut Hill	Chenango	Cayuga
Organic layer					
OM (%)	40.5	51.3	35.5	51.8	21.2
N (%)	1.51	1.30	0.95	1.47	0.69
OM ($Mg\ ha^{-1}$)	25.8	27.2	27.8	32.1	34.8
N ($kg\ ha^{-1}$)	978	696	755	898	1101
N/OM%	3.86	2.60	2.71	2.87	3.44
pH	4.01	3.72	4.56	3.93	4.03
Mineral soil (0–10 cm)					
OM (%)	7.8	7.3	7.9	13.3	12.5
N (%)	0.30	0.21	0.31	0.42	0.38
OM ($Mg\ ha^{-1}$)	48.9	46.0	55.7	69.4	69.5
N ($kg\ ha^{-1}$)	1889	1282	2156	2189	2132
N/OM%	3.85	2.81	3.88	3.16	3.05
pH	4.11	3.89	4.68	4.14	4.46
Exch H ($cmol\ kg^{-1}$)	28.2	25.6	24.2	38.4	29.7
Extr. P ($mg\ kg^{-1}$)	12.6	9.4	6.2	1.3	2.1
Extr. K ($mg\ kg^{-1}$)	52	34	79	59	63
Extr. Mg ($mg\ kg^{-1}$)	14	15	53	33	57
Extr. Ca ($mg\ kg^{-1}$)	70	66	450	178	554
P ($kg\ ha^{-1}$)	7.8	5.9	4.3	0.7	1.2
K ($kg\ ha^{-1}$)	33	22	56	31	35
Mg ($kg\ ha^{-1}$)	9	10	38	17	31
Ca ($kg\ ha^{-1}$)	44	42	322	96	305
Combined soil[a]					
OM ($Mg\ ha^{-1}$)	74.6	73.2	83.5	100.5	104.3
N ($Mg\ ha^{-1}$)	2.87	1.98	2.91	3.09	3.23

[a]Values may differ from sum of components owing to averaging and round-off error.

forest floor, large roots, and sites of obvious disturbance.

At each subsampling point, a 19.8 cm diameter sample was taken of the surface organic layer, defined to be the $F+H+A_{11}$ horizons. Within this sample area, five 4.5 cm diameter cores were taken to a depth of 10 cm and composited to represent the upper mineral soil. Bulk density was determined for each subsample as the dry weight of soil from this known volume, corrected for coarse fragments. Bulk density ranged from 0.49 to 0.95 Mg m^{-3}. Thus any errors or discrepancies in separating the layers do not greatly affect the sum of the two subsamples. Most organic layers were A_{11} material, with a thin F layer. Mineral soil samples were mostly A_{12} and upper B horizons. Fresh litter was discarded; generally, little was present because of its rapid incorporation into the F or A_{11}. A total of 520 subsamples, 260 of each depth, were taken and analyzed individually.

2.3. Laboratory procedures

All samples were air dried. Organic layer subsamples were weighed and ground in a hammermill. Mineral soil subsamples were crushed and sieved to separate the smaller than 2 mm fraction from the coarse fragments ($\geqslant 2$ mm). Each fraction was weighed; only the fine earth fraction was analyzed.

Organic matter mass of the organic layer was determined by loss on ignition in a muffle furnace (12–24 h at 480°C), corrected for moisture content. Organic matter percentage of the mineral soil was determined similarly, even though loss of structural water results in some overestimate (Ball, 1964). Such overestimation is small relative to the organic content (Table 2), however, and, moreover, would not appreciably affect differences between treatments at the same location.

Total N of all (organic layer and mineral soil) subsamples was determined by the Kjeldahl method. The 260 mineral soil subsamples were analyzed for cations and H^+ by the Department of Agronomy Soil Testing Laboratory using methods described by Greweling and Peech (1965). Readily extractable Ca, Mg, K and P were extracted using acetic acid–sodium acetate (Morgan's Solution) at pH 4.8. Exchangeable H was extracted using $BaCl_2$-triethanolamine. The pH of mineral soil subsamples was measured at 1:1 soil: water ratio, and a 1:10 ratio was used for organic layer subsamples.

All concentration data were converted to mass per unit area, correcting for the coarse fragment content of the mineral soil. Adding the respective masses of organic matter and N of the organic layer and mineral soil (to 10 cm) subsamples gave 'combined soil' values.

Nitrogen was expressed as a percentage of organic matter (N/OM%), using individual subsample masses of OM and N. This was used instead of a C:N ratio inasmuch as the standard factor of 1.724 overestimates organic carbon in these materials (Lunt, 1931; Ball, 1964; Howard, 1965; Ranney, 1969; Schlesinger, 1977).

In order to estimate cation exchange capacity, exchangeable cations were estimated from the extractable values using the regression equations developed by Stone (1975) and Young (1981) for similar soils. Cation exchange capacity was estimated from the sum of cations, adjusted as above, plus exchange acidity.

2.4. Statistical analysis

Mean plot values for the 16 soil parameters from three locations, Connecticut Hill, Chenango and Cayuga, were compared by ANOVA in a two-way classification (locations by fertilizer level). Combining the locations allowed inferences about the larger population of second-growth stands in the 'Southern Tier' of New York counties (Snedecor and Cochran, 1967). This combined analysis excluded the two Cattaraugus soils (Gilpin and Rayne) because of the computational difficulties attendant with the resulting unbalanced design. At the Chenango location, the four control plots were averaged into two by combining the respective values for the two higher basal area plots, and the two lower basal area plots. Comparisons between treatment means were made using orthogonal linear contrasts (Allen and Cady, 1982).

Mean values for soil variables at the five sites, regardless of treatment level, were compared using ANOVA and the Waller–Duncan k-ratio t test. Not surprisingly, the effect of location was significant for most soil parameters.

Soil variables were compared at the five experimental sites individually (treating the two Cattaraugus soils separately), using ANOVA for a completely randomized design with nested classification (Fryer, 1966; Snedecor and Cochran, 1967), although these results are not presented. Direct examination of the variability in soil properties within locations was made possible by keeping the subsamples separate.

3. Results

3.1. Organic layer

Mean organic matter mass of the controls differed little over the five sites, ranging from 25.8 to 34.8 Mg ha^{-1} (Table 2). Similarly, mean N contents varied only moderately from 696 to 1101 kg ha^{-1} (Table 2). The heavy application of fertilizer N had no significant effect on either organic matter or N mass. In both of the Cattaraugus soils, however, organic matter mass increased with treatment whereas N mass increased in one soil and decreased in the other (Figs. 2(a) and (b)).

Contrary to expectations, N as a percentage of organic matter decreased significantly with treatment (Table 3). Figure 3 reveals no consistent pattern. Cattaraugus-Gilpin and Cayuga decreased to the 672 kg ha^{-1} level whereas Cattaraugus-Rayne, Connecticut Hill and Chenango increased, with only the latter increase being significant. Thereafter N/OM% values at all locations decreased at the 1344 kg ha^{-1} level.

Although pH of the organic layer appeared to decline with increasing N, this was significant only at Connecticut Hill. At Cayuga, pH was higher on the N-treated plots although not significantly so.

3.2. Mineral soil and combined soil

The organic matter mass of the upper mineral soil ranged from 46 to 70 Mg ha^{-1}, regardless of sites or treatment (Fig. 2(a)). Average mass of N in the mineral soil of the control plots was remarkably similar at all locations, from 1889 to 2189 kg ha^{-1} excepting the Cattaraugus-Rayne site with only 1282 kg ha^{-1} (Table 2). ANOVA for the combined locations yielded no significant differences in organic matter percentage or mass, nor N percentage or mass, nor in N/OM% (Table 3). This was also true for organic matter and N masses of the combined soil layers (Table 3).

As was found with the organic layer, the lowest values for organic matter mass were at the two Cattaraugus locations, which increased with additions of fertilizer N. Only at Connecticut Hill did total N content increase with treatment and then not significantly (Fig. 2(b)). Although the mineral soil values of N/OM% appear to decrease with increasing additions of N fertilizer (Fig. 3), there were no statistically significant differences for any of the sites analyzed individually.

Both concentration and mass of extractable K, Mg and Ca in the mineral soil decreased with added N (Table 3). Estimates of significant decreases from control plots values (Table 4) indicate the reduction in extractable K, Mg and Ca associated with the N additions to be 11%, 45% and 54%, respectively. Deviations of individual N-treated plots from their respective control means are represented in Fig. 4. In accord with the decrease in extractable cations, pH also decreased significantly as a result of added N (Table 3).

Analyses of treatment effects on extractable P are confounded by inexplicably high values at Cattaraugus and Connecticut Hill. The range of P values for individual subsamples at Cattaraugus and Connecticut Hill precludes analytical error as an explanation. In any case, suspect samples were reanalyzed with the same results. Neither location is a known or likely spot for Indian fields. Surrounding farmlands were agriculturally abandoned from before P fertilization came into common practice, so contamination

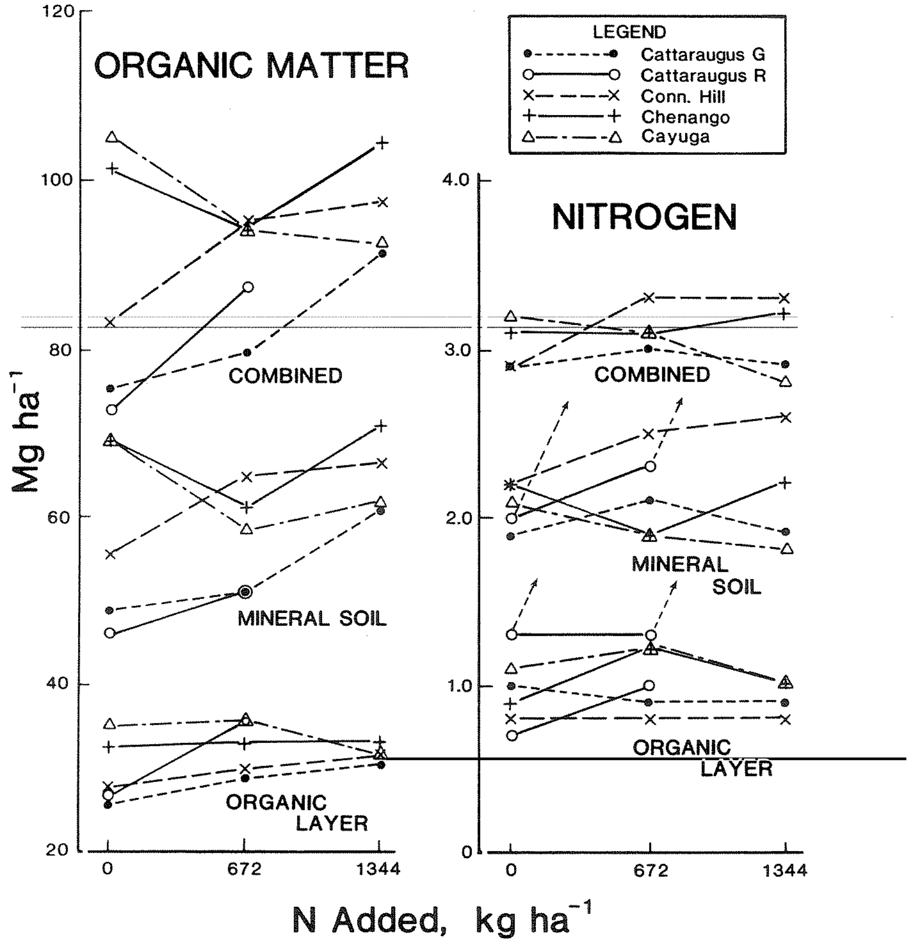

Fig. 2. The effect of added N on soil organic matter and N content (Mg ha^{-1}). (a) Organic matter (OM) mass; (b) N mass. (Arrows indicate low values that belong with the family of curves above.)

from dust is equally unlikely. The Cattaraugus location, however, is within the recorded extent of a large passenger pigeon (*Ectopistes migratorius* L.) nesting in 1823 (Schorger, 1955). The breeding colony stretched for 30 miles from the Allegheny River northward, with an average width of six miles. The high soil P levels might be residual from heavy dung accumulations reported in such nesting areas.

Whatever the explanation for the higher P levels at Cattaraugus and Connecticut Hill, there were no consistent trends with treatment. The notable feature is that N response of the overstory could not have been limited by lack of available P in these stands.

The fifth hypothesis postulated at the beginning of the study (i.e. variability too high for any conclusion) can be dismissed. Variability was indeed high both within and between replicate plots but was controlled to some degree. The coefficients of variation within location ranged from 11 to 24% for total N mass and 12 to 24% for organic matter mass above the 10 cm depth.

Further, no evidence supports hypotheses nos (1) and (2), that added N altered the total contents of N or organic matter within the most active soil layers (Table 3, Figs. 2(a) and (b)). Likewise, hypothesis no. (3), increased N/OM%, cannot be sustained (Table 3, Fig. 3). Rather, N/OM% of the mineral soil tended to decrease

Table 3
ANOVA for soil properties from the combined locations exclusive of Cattaraugus Gilpin and Rayne

Variable	Effect[a]		Contrast		R^2
	Location	Treatment[b]	Linear[c]	Quadratic[c]	
Organic layer					
OM (%)	**	NS	1.12	0.95	0.79
N (%)	**	NS	1.16	0.52	0.88
OM MASS	NS	NS	0.07	−0.42	0.14
N MASS	*	NS	0	−1.73	0.49
N/OM%	*	5.44*	−0.97	−3.15**	0.73
pH	*	NS	−0.32	0.22	0.43
Mineral soil					
OM (%)	**	NS	0.21	1.18	0.77
N (%)	*	NS	0.02	1.05	0.44
OM (MASS)	NS	NS	0.39	0.77	0.13
N (MASS)	NS	NS	0.15	0.63	0.36
N/OM%	**	NS	−0.91	0.13	0.91
pH	*	7.76*	−3.91	0.50	0.74
Exch. H (CONC)	**	NS	1.52	1.16	0.83
Extr. P (CONC)	**	NS	1.97	0.12	0.91
Extr. K (CONC)	*	3.76	−2.63*	0.77	0.56
Extr. Mg (CONC.)	NS	10.36*	−4.44**	1.02	0.68
Extr. Ca (CONC.)	*	3.85*	−2.77*	0.20	0.59
P (MASS)	**	NS	2.08	−0.75	0.94
K (MASS)	**	NS	−1.90	−0.29	0.85
Mg (MASS)	**	9.76**	−4.35**	0.77	0.74
Ca (MASS)	**	4.18*	−2.89*	0.13	0.64
Combined soil					
OM (MASS)	NS	NS	0.34	0.47	0.21
N (MASS)	NS	NS	0.16	−0.40	0.08

[a]Significant at $P=0.05$ level (*) or $P=0.01$ level (**).
[b]F values with (2,13) df.
[c]t values with 13 df.
MASS, Mass ha^{-1}; CONC., concentration, as in Table 2.

with treatment, although the change was not statistically significant.

With variability accounting for less than 25% of N applied at the 1344 kg ha^{-1} rate, hypothesis no. (4), no net retention of added N in the upper soil, is most nearly sustained.

4. Discussion

The five sites analyzed do not differ greatly in any measured property. The total masses of organic matter and N above the 10 cm depth range from 75 to 105 Mg ha^{-1}, and from 2.8 to 3.35 Mg ha^{-1}, respectively. The forest stands at these locations, while differing somewhat in species composition, were typical northern hardwoods of comparable size and diameter distribution (21–63 cm dbh). Essentially undisturbed for 45 years prior to treatment, organic matter and N returns in litter were probably similar and relatively stable (Miller, 1981).

The Cattaraugus-Rayne site had the lowest mineral soil organic matter content and lowest N/OM% of the five sites, and was the only one that appeared to accumulate N as a result of

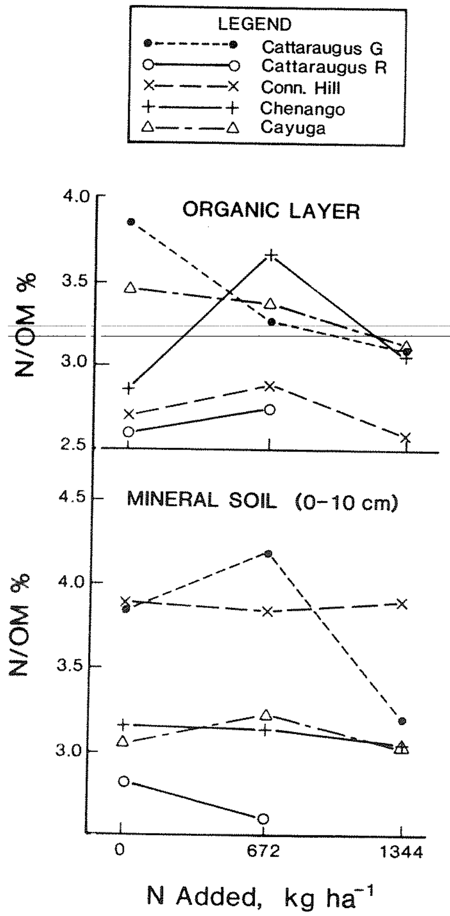

Fig. 3. Nitrogen as a percentage of organic matter (N/OM%) mass (Mg ha^{-1}), of the organic layer and the mineral soil.

treatment. Charred chestnut (*Castenea dentata* (Marsh.) Borkh.) stumps in the plots indicate that this site was burned by wildfire, before the origin of the present stand. A case can be made that the better drained Rayne soil supported a hotter fire in a dry autumn than occurred on the associated Cattaraugus-Gilpin soil, and so lost more of its N pool.

Aber et al. (1993) studied N-additions to northern hardwoods and attributed high N-retention capacity in their stands to sequestration in soil organic matter. Many of the stands at the Harvard Forest (Massachusetts) where they worked developed on old fields or pasture and likely were more N-limited than our stands.

With hypotheses of significant immobilization of added N in the upper soil rejected, and variability accounting for less than 25% of the 1344 kg ha^{-1} total application of N, an evident question is the fate of the remainder. Some fraction may be sequestered by the stand biomass although this is not apparent in either organic layer composition (Table 3) or growth response (Stanturf and Stone, 1985; Stanturf et al., 1989).

Loss through volatilization of NH_3 from these strongly acid soils (Tables 1 and 2) seems improbable except following the initial one application of urea at the Connecticut Hill site. Immobilization below the 10 cm depth of mineral soil following leaching or other transfer from the surface must be admitted as a possibility, although unconvincing in view of the unaltered N/OM% in the surface soil.

Denitrification offers an obvious loss pathway notably during the periodic occurrence of saturated soil or perched water tables above the fragipans characteristic of these soils (Fritton and Olson, 1972). Robertson and Tiedje (1984) reported denitrification rates from 2 to 12 kg-N ha^{-1} month^{-1} in certain hardwood stands in Michigan. The accepted value for this difficult-to-measure flux is generally less than 1 kg ha^{-1} year^{-1} in undisturbed stands (Gundersen, 1991).

Whether or not followed by dentrification, nitrification of NH_4 and nitrate leaching emerge as the most likely fates of N added in excess of plant uptake. Several studies have shown rapid movement of NH_4 and NO_3 through the forest floor following fertilization, though without much leaching beyond the rooting zone (Cole and Gessel, 1965; Overrein, 1971a, b; 1972; Mead and Pritchett, 1975a, b), presumably resulting from uptake by plants and microbes. The effectiveness of nitrification even in strongly acid forest soils has been well demonstrated (Bollen and Lu, 1968; Likens et al., 1977). Nitrification would be favored by the elevated NH_4 levels following application of ammonium nitrate (Wollum and Davey, 1975).

Fertilizer trials and studies with N-fixing species have shown elevated nitrate levels in soil solution (Van Miegroet and Cole, 1984; Johnson and Todd, 1988; Tschaplinski et al., 1991) and

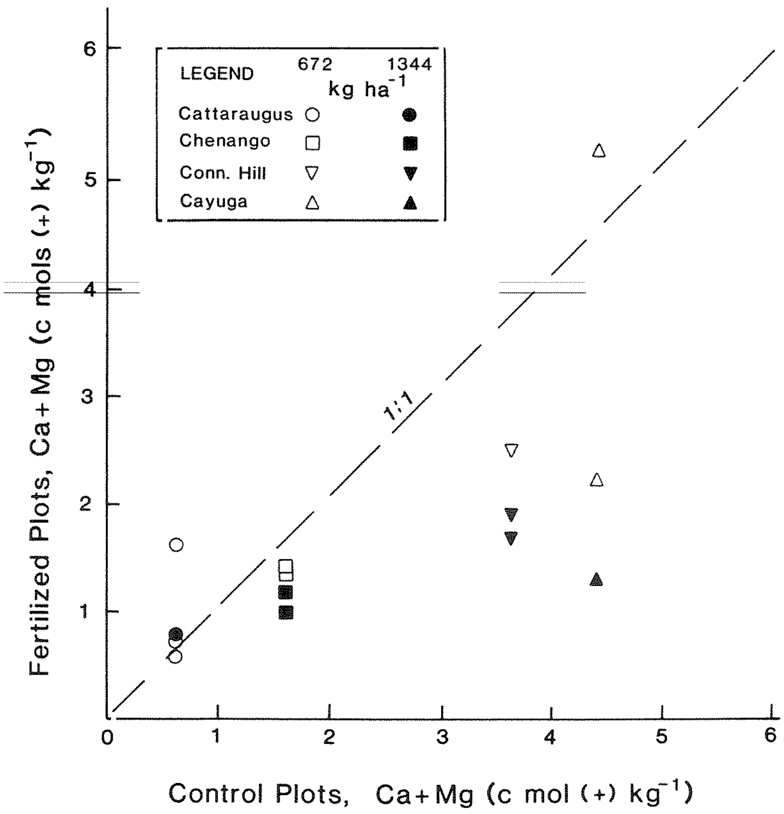

Fig. 4. Sum of the exchangeable cations (Ca+Mg) on the fertilized plots as compared with the mean values for the control plots at each location (cmol(+) kg^{-1}).

leaching of cations. Johnson (1992) concluded that single applications of large doses of fertilizer to N-deficient ecosystems would cause less nitrate leaching than frequent small inputs, such as from pollutant loading, because the latter more likely would favor the build-up of nitrifier populations.

Lowered concentrations and masses of extractable K, Mg and Ca in the N-treated plots concur with the hypothesis of nitrate leaching. Although the effect of treatment on pH of the forest floor was not consistent, pH of the mineral soil declined significantly with added N, further supporting the leaching hypothesis. Broadfoot (1966) noted that exchangeable K content decreased with annual applications of N to a young bottomland hardwood stand on a Sharkey clay soil. Van Miegroet and Cole (1984) reported that leaching was selective, with Ca being the major cation lost, followed by Mg and K, even though proportionally more Mg than K was leached relative to their exchangeable pools. We also found such selectivity, with 45% of the extractable Mg pool leached, as compared with 10% of the K pool (Table 4).

The estimated loss of base cations was modest relative to the amount of N added. The highest single application of N (672 kg ha^{-1}) provided far more anions (24 kmol(−) ha^{-1}) than needed to balance the estimated mean loss of base cations, 12.4 kmol(+) ha^{-1}. Initial loss of base cations from the forest floor, and possibly from

Table 4
Estimates of significant differences from mean control plot values of mineral soil (0–10 cm) characteristics resulting from treatments; based on analysis of the combined locations exclusive of Cattaraugus Gilpin and Rayne

Variable	Control mean	Estimate[a]	Standard error
pH	4.4	−0.4	0.09
Extr. P (mg kg^{-1})	3.2	1.2	0.62
Extr. K (mg kg^{-1})	62.9	−6.3	2.39
Extr. Mg (mg kg^{-1})	47.5	−21.1	4.75
Extr. Ca (mg kg^{-1})	394.2	−209.6	75.70
P (kg ha^{-1})	2.0	0.9	0.42
K (kg ha^{-1})	37.6	−3.9	2.03
Mg (kg ha^{-1})	28.7	−13.0	3.00
Ca (kg ha^{-1})	241	−129	44.70

[a]Negative estimates are that amount less than control plot mean; positive estimates are that amount greater.

the mineral soil, may have been appreciably higher than these estimates indicate. Return of base cations in litter over 5–10 year periods would have compensated somewhat for leaching losses, although no more than about 3 kmol(+) ha^{-1} $year^{-1}$, exclusive of K circulation (Chandler, 1941; Stone, 1975).

Since the mineral soil was sampled only to a depth of 10 cm it is quite possible that cation leaching continued to greater depths. Alternatively, ammonium nitrate in solution could have been carried in root channels, through the 0–10 cm layer, to react below. If this occurred, it would not have been uniform; both surface microrelief and the hand distribution of fertilizer would have introduced considerable variability. Both possibilities suggest that losses from the surface 10 cm probably underestimated total loss. If denitrification occurred at depth, however, the base cations leached from the upper horizons could have been retained in the landscape, if not within the profile from which they came.

Although the effect of N additions on the pH of the surface organic layer was not consistent, pH of the mineral soil declined significantly (Table 4). Binkley and Sollins (1990) have demonstrated that soil pH may vary without concomitant changes in base cation content when different species lead to different active acidities. In the present instance, however, neither species composition nor organic content of the upper soil was affected by treatment. Hence the lowered pH is attributable to the loss of base cations through nitrate leaching.

Most of the cation exchange capacity of the forest floor and upper mineral soil is pH dependent (Kalisz and Stone, 1980) thus the reduction in pH entails a loss in effective cation retention in addition to the associated loss of base cations. Figure 4 suggests the greater the quantity of base cations in the upper mineral soil, the greater the amount lost. At the Cattaraugus sites, however, the quantities in the controls were so low that detection of losses through field sampling was unlikely.

5. Conclusion

The ultimate fate of the added fertilizer N cannot be ascertained. It is not in the forest floor or upper mineral soil (0–10 cm), however, nor in the trees. It seems clear that on such soils, N added in excess of plant uptake capacity is not immobilized by long-term storage in soil organic matter despite the wide C:N ratio.

Inasmuch as the five experimental sites represent widespread soil types and stand conditions, different application dates, and a relatively large geographical range in southern New York, the results should be widely applicable there.

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References

Aber, J.D., Magill, A., Boone, R., Melillo, J.M., Steudler, P. and Bowden, R., 1993. Plant and soil responses to chronic nitrogen additions at the Harvard Forest, Massachusetts. Ecol. Appl., 3: 156–166.

Allen, D. and Cady, F.B., 1982. Analyzing Experimental Data by Regression. Lifetime Learning, Belmont, CA.

Ball, D.F., 1964. Loss-on-ignition as an estimate of organic matter and organic carbon in non-calcareous soils. J. Soil Sci., 15: 84–92.

Binkley, D. and Sollins, P., 1990. Factors determining differences in soil pH in adjacent conifer and alder–conifer stands. Soil Sci. Sci. Am. J., 54: 1427–1433.

Bjorkman, E., Lundberg, G. and Nommik, H., 1967. Distribution and balance of ^{15}N labelled fertilizer applied to young pine trees (*Pinus sylvestris* L.). Stud. For. Suec., 48: 1–23.

Bollen, W.B. and Lu, K.C., 1968. Nitrogen transformations in soils beneath red alder and conifers. In: J.M. Trappe, J.F. Franklin, R.F. Tarrant and G.M. Hansen (Editors), Biology of Alder. U.S., For. Serv., Pacific Northwest For. Range Exp. Stn., Portland, OR, pp. 141–148.

Broadfoot, W.M., 1966. Five years of nitrogen fertilization in a sweetgum–oak stand. U.S., For. Serv., Res. Note S0-34.

Chandler, R.F., 1941. The amount and mineral nutrient content of freshly fallen leaf litter in the hardwood forests of central New York. J. Am. Soc. Agron., 33: 859–871.

Cole, D.W. and Gessel, S.P., 1965. Movement of elements through forest soil as influenced by tree removal and fertilizer additions. In: C.T. Youngberg (Editor), Forest–Soil Relationships in North America. Oregon State University, Corvallis, OR, pp. 95–104.

Fritton, D.D. and Olson, G.W., 1972. Depth to the apparent water table in 17 New York Soils from 1963 to 1970. Cornell Univ. Agric. Exp. Stn. N.Y. Food Life Sci. Bull. 13 (Agron 2): 1–40.

Fryer, H.C., 1966. Concepts and Methods of Experimental Statistics. Allyn and Bacon, London.

Greweling, T. and Peech, M., 1965. Chemical soil tests. Cornell Univ. Agric. Exp. Stn. Bull 960, Ithaca, NY.

Gundersen, P., 1991. Nitrogen deposition and the forest nitrogen cycle: Role of denitrification. For. Ecol. Manage., 44: 15–28.

Henderson, G.S. and Harris, W.F., 1975. An ecosystem approach to characterization of the nitrogen cycle in a deciduous forest watershed. In: B. Bernier and C.H. Winget (Editors), Forest Soils and Forest Land Management. Les Presses de l'Universite, Quebec, pp. 179–193.

Howard, P.J.A., 1965. The carbon–organic matter factor in various soil types. Oikos, 15: 229–236.

Jansson, S.L., 1958. Tracer studies on nitrogen transformations in soil with special attention to mineralization–immobilization relationships. K. Lantbrukshoegsk. Anal., 24: 101–361.

Johnson, D.W., 1992. Nitrogen retention in forest soils. J. Environ. Qual., 21: 1–12.

Johnson, D.W. and Todd, D.E., 1988. Nitrogen fertilization of young yellow-poplar and loblolly pine plantations at different frequencies. Soil Sci. Soc. Am. J., 52: 1468–1477.

Kalisz, P.J. and Stone, E.L., 1980. Cation exchange capacity of acid forest humus layers. Soil Sci. Soc. Am. J., 44: 407–413.

Likens, G.E., Bormann, F.H., Pierce, R.S., Eaton, J.S. and Johnson, N.M., 1977. Biogeochemistry of a Forested Ecosystem. Springer, New York.

Lunt, H.A., 1931. The carbon–organic matter factor in forest soil humus. Soil Sci., 32: 27–33.

Mead, D.J. and Pritchett, W.L., 1975a. Fertilizer movement in a slash pine ecosystem. I. Uptake of N and P and N and P movement in the soil. Plant Soil, 43: 451–465.

Mead, D.J. and Pritchett, W.L., 1975b. Fertilizer movement in a slash pine ecosystem. II. N distribution after two growing seasons. Plant Soil, 43: 467–478.

Miller, H.G., 1981. Forest fertilization: Some guiding principles. Forestry, 54: 157–167.

Miller, H.G., Miller, J.D. and Pauline, O.J.L., 1976. Effect of nitrogen supply on nutrient uptake in Corsican pine. J. Appl. Ecol., 13: 955–966.

Mitchell, H.L. and Chandler, R.F., 1939. The nitrogen nutrition and growth of certain deciduous trees of northeastern United States. Black Rock For. Bull., 11: 1–94.

Overrein, L., 1971a. Isotope studies on the leaching of different forms of nitrogen in forest soils. Medd. Nor. Skogsforsoeksves., 106: 335–351.

Overrein, L., 1971b. Isotope studies on nitrogen in forest soils. I. Relative losses of nitrogen through leaching during a period of forty months. Medd. Nor. Skogsforsoeksves., 114: 261–280.

Overrein, L., 1972. Isotope studies on nitrogen in forest soil. II. Distribution and recovery of ^{15}N-enriched fertilizer nitrogen in a 40-month lysimeter experiment. Medd. Nor. Skogsforsoeksves., 122: 307–324.

Raney, W.A., 1960.The dominant role of nitrogen in leaching losses from soils of humid regions. Agron. J., 52: 563–566.

Ranney, R.W., 1969. An organic carbon–organic matter conversion equation for Pennsylvania surface soils. Soil Sci. Soc. Am. Proc., 33: 809–811.

Robertson, G.P. and Tiedje, J.M., 1984. Denitrification and nitrous oxide production in successional and old-growth Michigan forests. Soil Sci. Soc. Am. J., 48: 383–389.

Safford, L.O., 1974. Effect of fertilization on biomass and nutrient content of fine roots in a beech–birch–maple stand. Plant Soil, 40: 349–363.

Schlesinger, W.H., 1977. Carbon budgets in terrestrial detritus. Annu. Rev. Ecol. Syst., 8: 51–81.

Schorger, A.W., 1955. The Passenger Pigeon. University Wisconsin, Madison.

Snedecor, G.W. and Cochran, W.G., 1967. Statistical Methods, 6th edn. Iowa State University, Ames.

Stanturf, J.A., 1983. Effects of added nitrogen on trees and soil of deciduous forests in southern New York. Ph.D. Thesis, Cornell University, Ithaca, NY.

Stanturf, J.A. and Stone, E.L., 1985. Measuring fertilizer response in mixed species hardwood stands. In: J.O. Dawson and K.A. Majerus (Editors), Proc. Fifth Central Hardwood Forest Conf., 15–17 April 1985, Department Forestry, University of Illinois, Urbana-Champaign, IL. pp. 78–89.

Stanturf, J.A., Stone, E.L., and McKittrick, R.C., 1989. Effects of added nitrogen on growth of hardwood trees in southern New York. Can. J. For. Res., 19: 279–284.

Stone, Jr., E.L., 1975. Windthrow influence on spatial heterogeneity in a forest soil. Mitt. Eidgen. Anst. Forstl. Versuchsanst., 51: 77–87.

Stone, Jr., E.L. and Kszystyniak, R., 1977. Conservation of potassium in the *Pinus resinosa* ecosystem. Science, 198: 192–194.

Switzer, G.L. and Nelson, L.E., 1972. Nutrient accumulation and cycling in loblolly pine (*Pinus taeda* L.) plantation ecosystems: The first twenty years. Soil Sci. Soc. Am. Proc., 36: 143–147.

Tamm, C.O., 1971. Primary production and turnover in a spruce forest ecosystem with controlled nutrient status (A Swedish IBP project). II. The experiment at Strasan, Svardsjo, and some remarks on the value of so-called optimum nutrition experiments. Bull. Ecol. Res. Comm. Stockholm, 14: 127–145.

Terman, G.L., 1977. Quantitative relationships among nutrients leached from soils. Soil Sci. Soc. Am. J., 41: 935–940.

Tschaplinski, T.J., Johnson, D.W., Norby, R.J. and Todd, D.E., 1991. Biomass and soil nitrogen relationships of a one-year old sycamore plantation. Soil Sci. Soc. Am. J., 55: 841–847.

Ulrich, B., 1976. Fate of applied nutrients in forest ecosystems. In: Proc. XVI IUFRO World Congress, Vol. 1. IUFRO Secretariat, Oslo, Norway, pp. 106–113.

Van Miegroet, H. and Cole, D.W., 1984. The impact of nitrification on soil acidification and cation leaching in a red alder ecosystem. J. Environ. Qual., 13: 586–590.

Wollum, A.G. and Davey, C.B., 1975. Nitrogen accumulation, transformation, and transport in forest soils. In: B. Bernier and C.H. Winget (Editors), Forest Soils and Forest Land Management. Les Presses de l'Universite, Quebec, pp. 67–108.

Young, W.R., 1981. Effect of different tree species on soil properties in central New York. M.S. Thesis, Cornell University, Ithaca, NY.

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